

CHAPTER III

SECTION 4B.0

EDDY CURRENT DEICING SYSTEMS

CHAPTER III—ICE PROTECTION METHODS

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SYMBOLS AND ABBREVIATIONS

Symbol	Description
ac	Alternating Current
°C	Degrees Celsius
dc	Direct Current
ECDS	Eddy Current Deicing System
EEDS	Electro-Expulsive Deicing System
EIDI	Electro-Impulse Deicing System
EMI	Electromagnetic Interference
°F	Degrees Fahrenheit
FAA	Federal Aviation Administration
SCR	Silicon Controlled Rectifier
V	Volts
Vac	Volts Alternating Current
Vdc	Volts Direct Current

III.4B. EDDY CURRENT DEICING SYSTEMS.

III.4B.1. OPERATING CONCEPTS AND COMPONENTS.

Eddy Current Deicing Systems (ECDS) are classed as electromechanical ice protection systems. Accreted ice is expelled from blanket-protected structures by a strong, rapid outward thrust of the blanket surface. This impulse movement is in reaction to electrical current being pulsed through flattened planar coils embedded within and spanwise along the leading edge of the surface, to be protected (figure III 4B-1). Over the coil, and separated by an insulation layer, is a conductive target material; over the target layer is a surface erosion layer. The large-pulsed currents in the coils induce opposite flowing eddy currents in the conductive target material and these opposing electrical currents (eddy current repulsion) cause the target material, and the outer surface to momentarily move away from the coil (figure III 4B-2). Reference 4B-1 presents a detailed discussion of this eddy current repulsive force and reference 4B-2 describes the ECDS theory of operation more completely. Actual surface movement is minimal but the acceleration is very rapid. The acceleration debonds and shatters any ice accreted on the outer surface layer. Ice removal is accomplished by aerodynamic forces, inertial forces, or gravity.

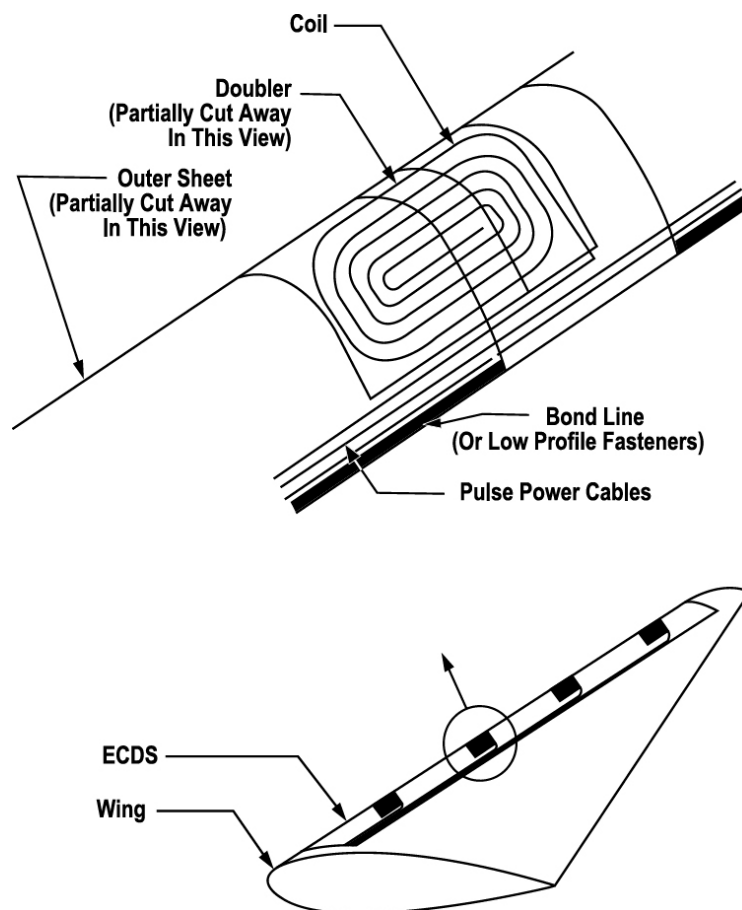


FIGURE III 4B-1. ECDS PLANAR COIL

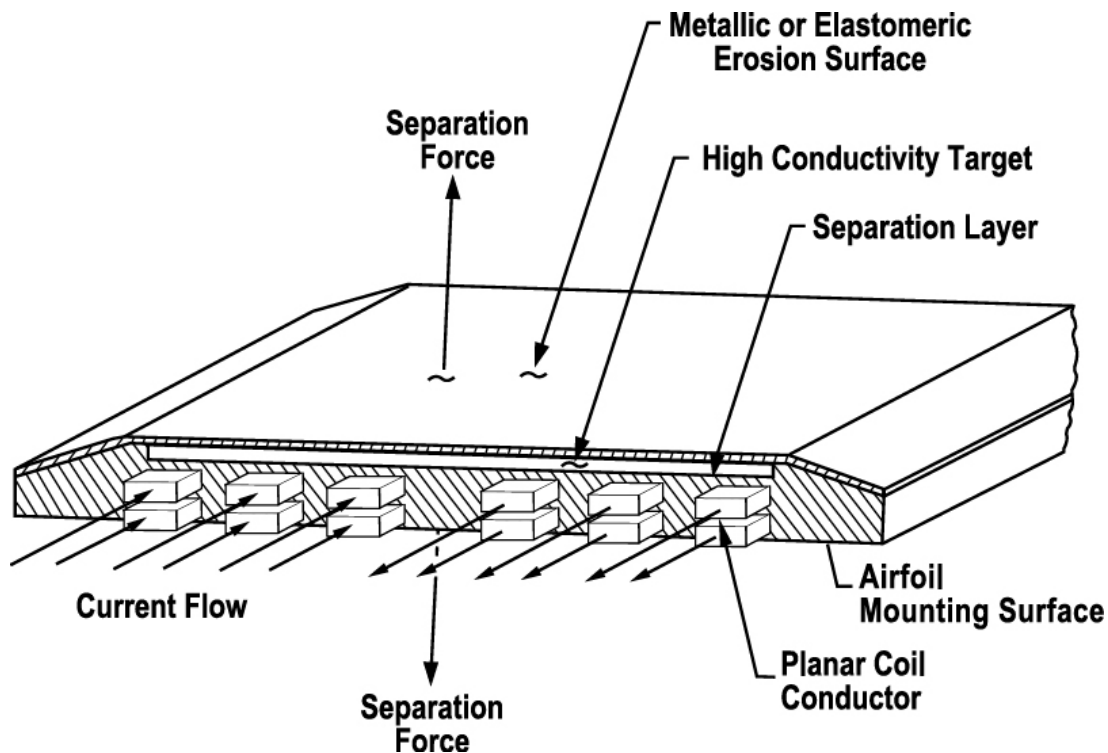


FIGURE III 4B-2. ECDS BLANKET ASSEMBLY

The rapid movement of the outer erosion surface and the debonding, shattering, and airflow removal of accreted ice are all actions that are quite similar to those produced by Electro-Impulse and Electro-Expulsive deicing systems; however, the designs that cause the outer surface to accelerate outward are different. In the Electro-Impulse Deice system (EIDI), eddy current repulsion is also used (reference 4B-3), but circular, not planar, ribbon coils are individually attached to the aircraft frame, and eddy currents are induced in the aircraft's skin surface. With Electro-Expulsive Deice Systems (EEDS), an electrical current is pulsed in opposite directions through closely-spaced parallel conductors, and an electromagnetic force is created that forces the conductors apart, imparting an outward force to a moveable outer erosion surface.

In addition to the blankets and coils, other functional components in an ECDS are:

- aircraft power converter for capacitor charging current (dc),
- capacitor charging control logic and capacitors for energy storage,
- capacitor energy distribution logic and switching circuits to coils,
- cockpit control panel.

Specific configurations can vary between manufacturers and design requirements. For example, in small aircraft the control logic and the energy charging, storage, switching, and distribution functions can all be configured within the power converter module and located in the fuselage (figure III 4B-3). In larger aircraft, multiple modules can be used for capacitors and switching

circuits to establish branches that would minimize the high-voltage wiring runs to the coils (figure III 4B-4).

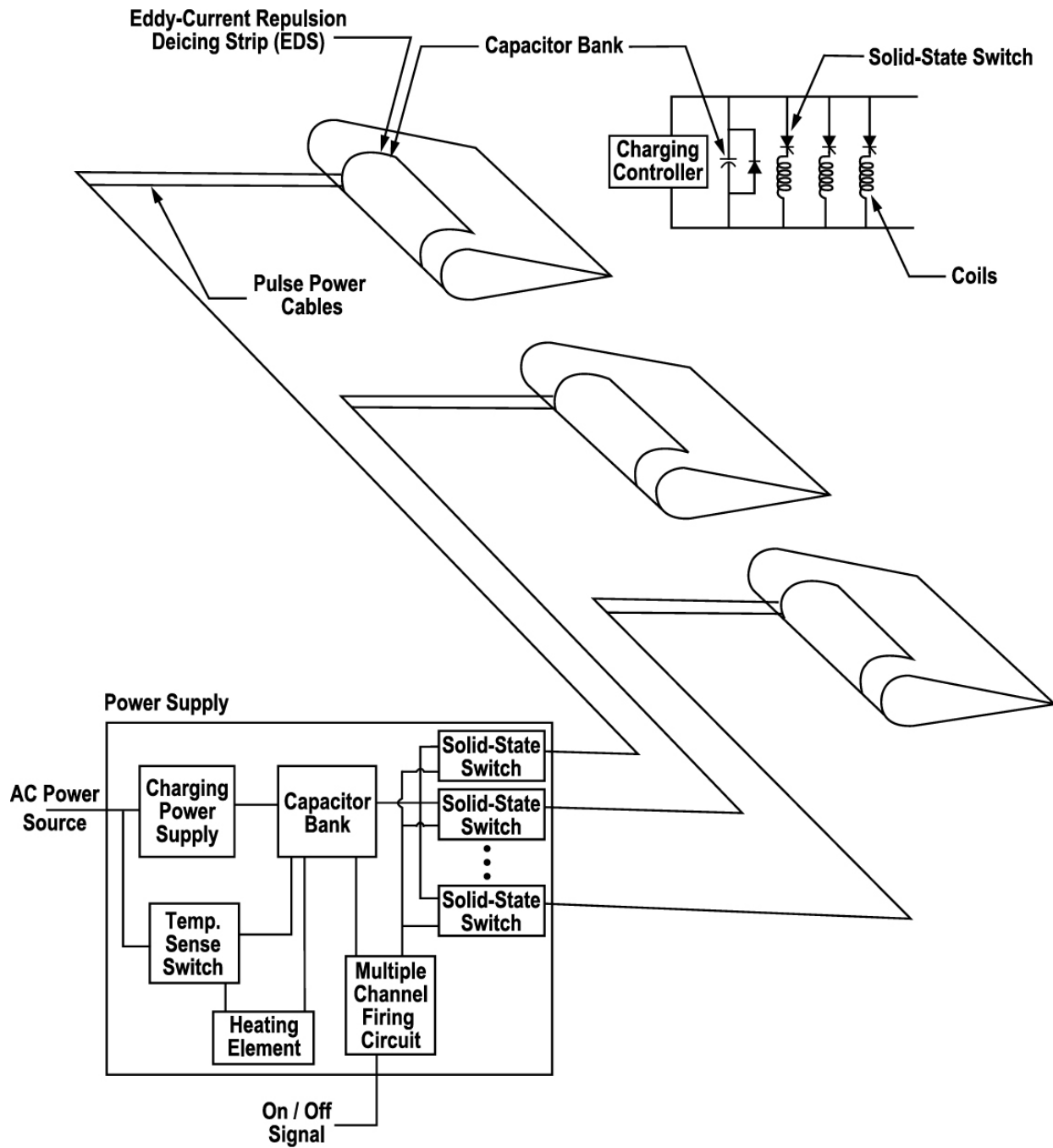


FIGURE III 4B-3. ECDS MINIMUM SYSTEM

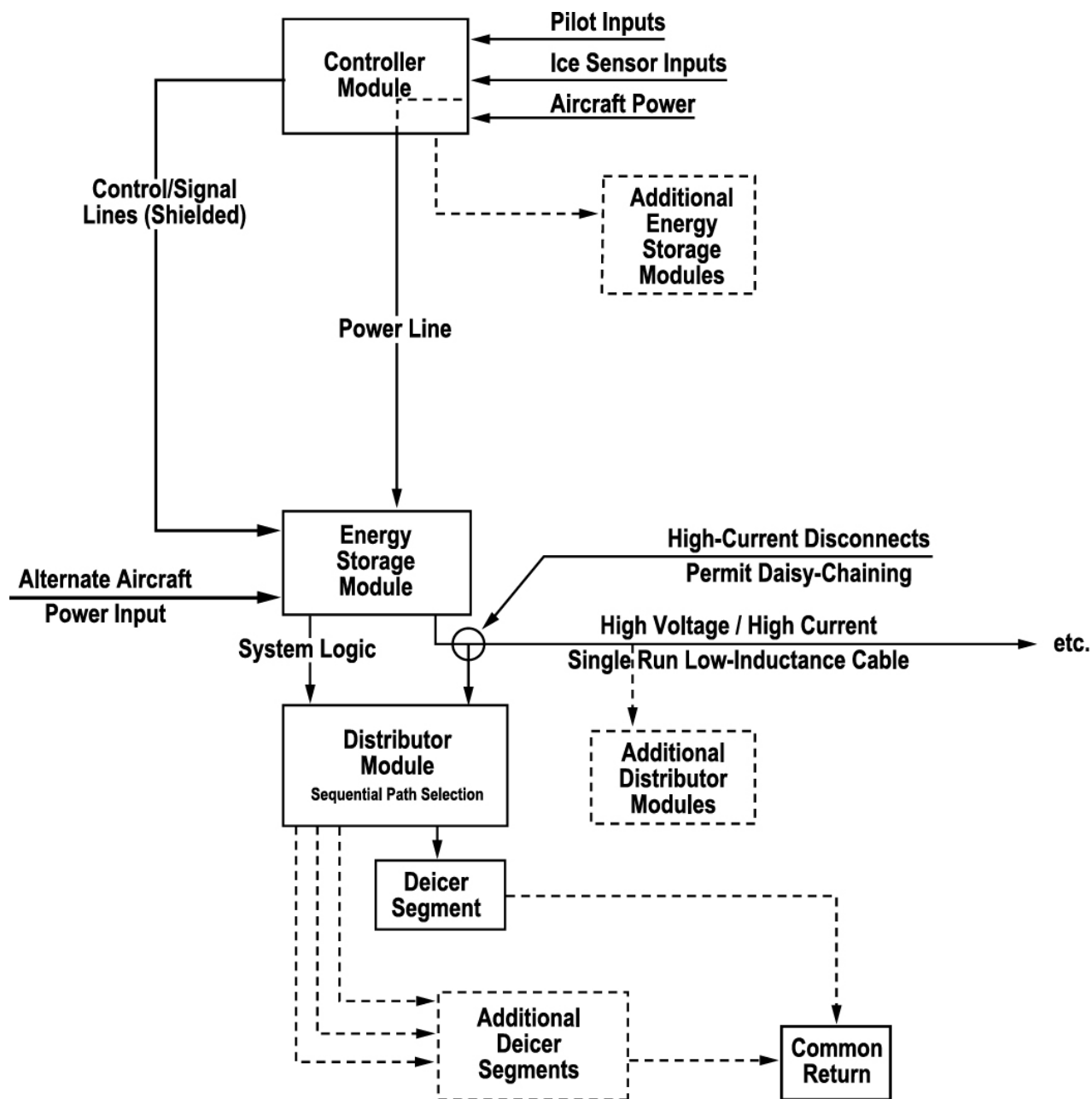


FIGURE III 4B-4. ECDS COMPLEX SYSTEM

Miscellaneous components include high-current, low-inductance coaxial cabling, electrical interface wiring, connectors, and the appropriate circuit breakers and/or fuses. All of the operating equipment can usually be tailored to operate in either 28 Vdc, 115 Vac single-phase, or 115/200 Vac three-phase configurations.

III.4B.2 DESIGN GUIDANCE.

III.4B.2.1 Deicer Blanket.

Deicer blankets, also referred to as gloves, differ somewhat in construction among manufacturers, but basically the designs consist of one or more flattened planar coils spaced spanwise to cover the surface to be protected, and a thin metallic “target” sheet positioned over the coils but separated by an insulation layer. The outer surface of the blanket may be metallic or elastomeric (polyurethane or neoprene), depending upon the application. The metallic-surfaced blanket is more difficult to install but has better erosion characteristics and fewer maintenance concerns. The elastomeric surfaced blanket is easier to install and more applicable to retrofit applications.

The target sheet is free to move only slightly outward, and is restrained in the spanwise and chordwise direction. An alternative approach would be to configure the blanket layers such that the coil accelerates away from the target material. In this case, the target sheet would be attached to the airfoil and the coil (layer) would be free to deflect outward. The deicing principle would be the same. The target sheet must be made from a highly conductive material to achieve strong eddy currents. Solid copper sheet provides excellent conductivity; aluminum provides about half that of copper. However, neither is extremely pliable. Solid beryllium copper alloy sheet can provide high-electrical conductivity and good strength. Woven mesh is less conductive than the materials already mentioned but is extremely flexible. A tradeoff must be made with respect to weight and thickness when selecting the material and configuration.

Typically, the deicing blanket is bonded onto the leading edges of airfoils in much the same manner as pneumatic deicers or electrothermal propeller deicers. This technique lends itself well to solid composite or metallic structures, where access is limited to the outer surface. Retrofit operations are also facilitated because modification to the existing airfoil is generally not required, although small access ports in the aircraft surface are needed for the electrical cables.

Installation is more critical for some airfoils than others. An airfoil’s characteristics are defined primarily by the shape of the camber line. By adding leading-edge material, such as the deicing blanket, the camber line and, therefore, the airfoil is being modified to something different than originally designed. In the case of larger commercial transports and new commuter and general aviation aircraft, which utilize highly optimized laminar-flow wings, the preferred installation would be to supply the blanket as one original equipment unit. Retrofitting the deicing blanket to a highly optimized laminar section takes careful analysis, design, and installation. The best design criteria here is to design the add-on section as closely to the original leading-edge shape as possible and, in doing so, make sure that the new camber line blends in with the old as smoothly as possible and that the leading-edge pressure gradient is consistent with the original shape. Surface discontinuities or changes in slope, which may result in boundary layer disturbances and increased drag, should be avoided.

Attaching the blanket to the aircraft with flexible adhesive works well. Adhesives shown to work are Hexcel 3140 urethane and flexible epoxies such as Hysol 9340 or 3M 2216. Hard fasteners are not recommended for most installations due to the high acceleration forces

involved. An exception is locations where the glue bond line may be peeled. Adhesives have high shear strength, but little peel strength. For instance, one or two small rivets may be placed at the corners of the bond line through the outer alloy skin and the aircraft surface. The use of bolts should be avoided. Even the head thickness (0.10" or 2.5 mm) of a countersunk AN525/10-32 R7 screw may be unacceptable for critical airfoils.

A small aircraft may have three blanket sections with four coils each: one blanket on each wing and one on the tail. The power supply would automatically pulse all 12 separate coils in sequence at a designated firing cycle (figure III 4B-3). Ice removal is most efficient if each coil is pulsed twice in a row. To achieve the thinnest possible cross-section, the coils are typically made from flattened braid wire, or thin foil which has been chemically etched to the coil configuration in a process similar to the manufacture of printed circuit boards. The impedance of the coil must be closely controlled for a given power supply and pulse power cables. For example, the coil used with a 500-volt power supply must have a much lower impedance than a coil with a 2000-volt power supply. Linear circuit theory yields the optimum coil density. Basically, the coil must have enough impedance (turn density) so that the capacitor energy is sufficiently transferred to the coils, but not so much impedance that the system becomes too slow and stops producing the high acceleration forces that remove ice. Higher turn density coils have a higher impedance. Such a coil uses most of the capacitor energy but may slow the electrical current down too much. The resulting low acceleration of the blanket outer skin will not remove thinner ice. A coil with a low turn density reacts quickly but does not use most of the capacitor stored energy.

III.4B.2.2 Energy Distribution Module.

This module distributes a high-voltage, high-current, narrow-width pulse to the coils in the blanket segments via gating circuits and multiple cables. The gating circuits can be electromechanical stepping switches or silicon controlled rectifiers (SCR).

The energy distribution module is a high voltage/high current-carrying device; thus, wire sizing and run distance are quite critical between each energy storage module and its family of energy distribution modules and blankets. The ohmic drop and inductive reactance in the wiring must be small compared to the impedance of each blanket segment. The module may be located within a few feet of the blanket lead exits to minimize weight.

Multiple cables connect associated blanket segments to their energy distribution module, which is connected by high-current disconnects to a single run of low-inductance cable leading to its associated energy storage module. Multiple high-current disconnects along this single run of low-inductance cable can be used to daisy chain energy distribution modules.

III.4B.2.3 Energy Storage Module.

This module is an electronic driver assembly that stores the blanket-firing energy in capacitors and, as directed by the controller sequencing logic, fires the high-voltage pulses that are directed through switching circuits to various blanket deicer segments via the energy distribution modules. Voltage levels vary among types and required coverages, and can range from around

200 Vdc for simple, minimal systems to nearly 2000 Vdc for complex, extensive systems. The time required to charge the capacitor is a function of the final voltage, and a “typical value” is approximately 2 seconds.

III.4B.2.4 Controller Module.

This module receives pilot and optional ice sensor inputs, contains the logic circuits for monitoring and self-test functions, and, in general, is used to direct the operations of the deicing system. On some types, aircraft power is input to the controller and converted to capacitor charging current. On other types, this function may be part of the energy storage module. The wiring run distance between the controller module and each energy storage module is not critical and a single run of shielded cable can contain both heavy-current/low-inductance power lines and control signal lines. One controller module can monitor and operate all ECDS system hardware, although additional controller modules may be included to meet redundancy requirements. For very simple systems, the controller, energy storage, and energy distribution functions can all be combined into a single assembly.

III.4B.3 USAGES AND SPECIAL REQUIREMENTS.

III.4B.3.1 Airfoil and Leading Edges.

The ECDS can be adapted to virtually any airfoil or leading edge. The blankets are attached to the airfoil in much the same manner as standard pneumatic deicer boots. Blankets must always be blended smoothly to any airfoil surfaces to avoid step disturbances in the boundary layer and excess drag. Additionally, the blanket can also be designed and manufactured as a complete leading-edge assembly and be installed as such.

Allowable ice thickness must also be considered. The system can prevent the buildup of ice greater than 0.10” (2.5 mm). The pilot (or ice detector) can always turn the system on safely; a threshold thickness does not have to be obtained.

III.4B.3.2 Windshields.

The eddy current blankets are not optically clear and thus are not appropriate for windshield ice protection.

III.4B.3.3 Engine Inlet Lips and Components.

Although eddy current deicers have not been installed on production engine inlets, they can be fitted to engine inlet lips and other components such as splitters or guide vanes. Consideration must be given to the design for complex shapes so that the target and coils conform to the contour of the shapes. In this application, the deicer blanket would likely be formed to the contour prior to installation. Several coils should be placed radially around the inlet. Generally, coils are placed in redundant pairs. Typical coil spacing is 18” between each coil. Coils can be placed directly on the ice formation surface or just behind the leading edge for radii sharper than 0.75” (19 mm). The outer metal strip of the deicer blanket, typically aluminum or titanium alloy, is formed between dies or stretch-formed over a male die.

Preliminary testing for shed particle size and thickness has been done as part of Air Force/NASA ice protection tests (reference 4B-4). See figure III 4B-5. For the two icing conditions included in this test, firing each coil every 2 minutes or less kept shed particle thickness below 0.10" (2.5 mm). More frequent firings may assure thinner shed-ice particles.

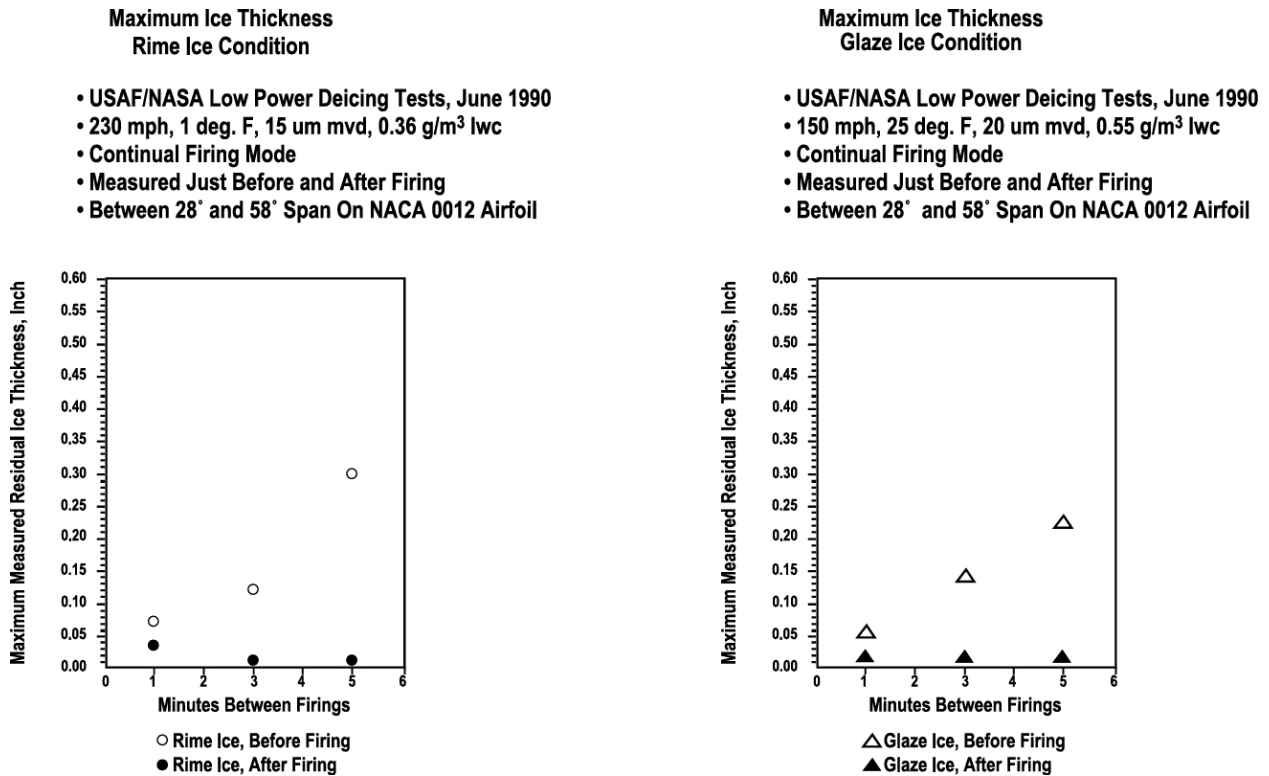


FIGURE III 4B-5. DESIGN OF ECDS CYCLING TIME

III.4B.3.4 Turbopan Components.

Suitability of the ECDS for turbopan components has not been evaluated.

III.4B.3.5 Propellers, Spinners, and Nose Cones.

The configuration of the eddy current propeller deicer is similar to that of an electrothermal propeller deicer in terms of thickness, area, and installation (figure III 4B-6). However, more development testing is needed to establish blanket criteria for withstanding erosion, centrifugal loads, and blade flexing. It is probable that the blade and the deicing system must be integrally designed. The energy storage unit and control module could be located on the nonrotating side of the hub and the distributor on the rotating side. The connecting means between the two could be a slip-ring assembly mounted to the hub. The slip ring would be similar to those used with electrothermal propeller deicing, except that it would be rated for the higher voltage. It is important to mount the energy storage unit as close as possible to the distributor and deicer to minimize line losses.

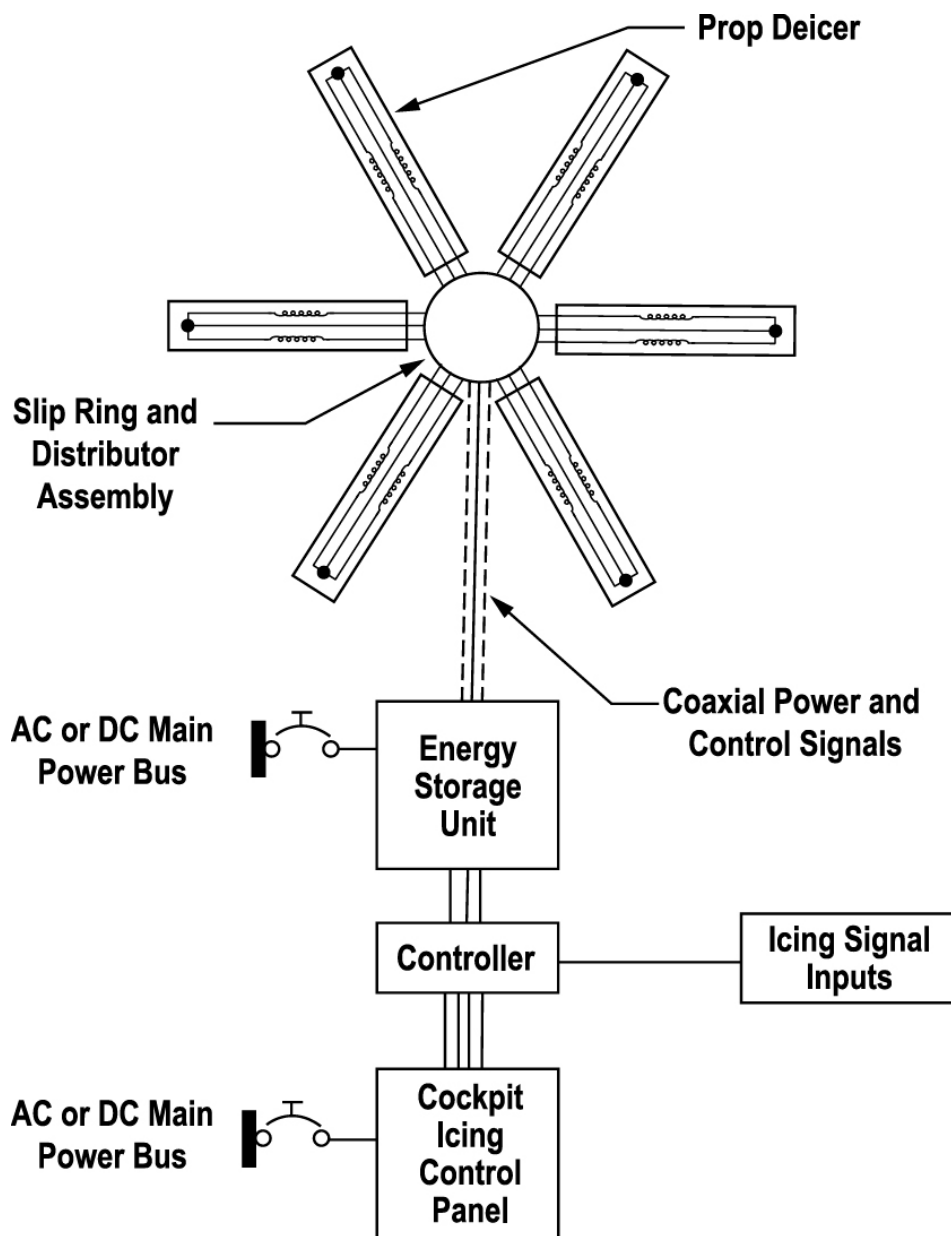


FIGURE III 4B-6. ECDS PROPELLER BLOCK DIAGRAM

Suitability of the system for spinners and nose cones has not been completely evaluated. Nonrotating nose cones can be wired in the same manner as wing leading-edge coils. Rotating cones or spinners require slip rings rated for transmitting the high-current pulse from the power supply to the coils. Laboratory testing of such slip rings has been done (reference 4B-5). Alternatively, a small capacitor/power supply can be installed within the nose cone as indicated in reference 4B-3.

III.4B.3.6 Helicopter Rotors and Hubs.

Eddy current deicing for helicopter rotors and hubs has not gone beyond the concept stage. See the discussion of propeller deicing, section III 4B.3.5.

III.4B.3.7 Flight Sensors.

Eddy current protection for aircraft flight sensors is not suitable. In general, protecting a small and delicate flight sensor can best be accomplished by thermal means.

III.4B.3.8 Radomes and Antennas.

In general, the conductors embedded in eddy current blankets cannot be used to cover those portions of radomes that must be transparent to radar frequencies or to surround those portions of an antenna that must radiate. In fact, before using eddy current blankets in close proximity to radiating fields, a careful analysis must be performed to ensure that side lobes and fringing effects do not degrade intended operation (references 4B-6 and 4B-7).

III.4B.3.9 Miscellaneous Intakes and Vents.

Eddy current blankets can be used on intakes and vents in accordance with the same guidelines as previously discussed for engine inlets. Since failure modes are less significant than for an engine inlet, some of the restrictions can usually be relaxed to produce a less expensive solution.

III.4B.3.10 Other.

Struts, pylons, wheel covers, tail assemblies, and other aircraft surfaces where ice forms are candidates for the ECDS. Blankets can also be installed in areas that must be routinely accessed but are subject to freezing rain or other forms of ground icing. Latches, access doors, and inspection ports are typical examples. The blankets are fired manually when access is required during or after icing conditions.

III.4B.4 WEIGHT AND POWER REQUIREMENTS.

Low-power requirements for the ECDS have been documented in testing at the NASA-Lewis Icing Research Tunnel (reference 4B-4). Weight and power requirements vary depending upon the application and the manufacturer's design. Weight and power requirements both increase with the extent of protection needed (aircraft size, wings, empennage, engine inlets, etc.), and power requirements increase as the firing cycle is shortened. As a very general guideline, weight estimates vary from 50 pounds for minimum applications to 500 pounds for maximum applications. Power estimates range from 0.015 watts/sq. in. of coverage for a large aircraft using a 3-minute firing cycle to 0.7 watts/sq. in. using a 1-minute firing cycle.

III.4B.5 ACTUATION, REGULATION, AND CONTROL.

Several methods of actuation and control are possible, depending on the level of sophistication desired. In the simplest form, the pilot activates the system through a cockpit control switch.

Upon power-up, the system automatically checks for short circuits, ground faults, and open electrical circuits, and then sequences through the deicing cycles at a preset rate. Although all protected surfaces may not be visible to the pilot, he need not be concerned lest he turn on the system with “too small” an ice buildup, since a minimum ice buildup does not have to occur before deicing.

In a more sophisticated configuration, the control logic receives input signals from an icing rate detector and selects a firing cycle accordingly. With this method, it is necessary that ice accretion at the sensor be representative of the most critical areas to be protected. The same signal can be used to notify the pilot when icing conditions begin. Choice of configuration requires consideration of operational requirements in light of weight, cost, and pilot involvement.

A self-test mode can be included in the control logic which can either be pilot initiated or automatically initiated. The test cycles through all the system circuitry and any deviation from the functional requirements activates a cockpit warning light.

III.4B.6 OPERATIONAL USE.

A system preflight checkout is recommended. This checkout can be conducted in either of two ways. The first employs a self-test mode which automatically cycles every deice zone and monitors circuit and system integrity. (This method can also be used as an in-flight system check.) The second method of preflight checkout is best suited to smaller systems. One places his hand on blanket surfaces to ensure that each blanket segment is firing and also listens for audible differences that should be evident for faulty segments.

There is no minimum or maximum ice thickness required or recommended for activation. Operationally, the system should be activated in accordance with existing Federal Aviation Administration (FAA) regulations which call for turn-on whenever visible moisture is present and the temperature is below 50°F (10°C). Simple systems might merely have a power on/off switch. More complex systems might have an off/auto/manual-on/self-test selector switch plus a display of system status and icing rate. In the ON and AUTO modes the system would cycle continuously on a predetermined basis until the system was placed in the OFF mode. In MANUAL-ON mode the system would operate for one complete cycle of all respective deice zones. The predetermined cycle time is a matter of requirement and designed logic circuits. The firing rate of each segment is controlled by the maximum ice particle size that is desired by the systems designer. A leading edge that accretes ice rapidly, or an engine inlet that must expel only small particles of ice, would require more frequent firing than other areas that might accrete ice more slowly or do not present a structural impingement problem. Typically, 1-, 2-, and 3-minute cycle times are used, but the system has the capability to operate with different cycle times assigned to different deicer segments.

III.4B.7 MAINTENANCE, INSPECTION, AND RELIABILITY.

The lack of operational and service experience precludes a general statement of maintenance requirements or reliability. Periodic visual inspection of blanket surfaces is recommended for

detection of weathering, foreign object damage, or fatigue cracks. Small nicks or cuts can usually be repaired “on aircraft,” thus preventing aerodynamic penalties from surface roughness and also preventing small flaws from growing. If a deicer segment fails or is damaged, the erosion layer is removed, a replacement segment is installed, and a new top layer is installed to complete the repair.

No routine maintenance of the electronic modules is required. All modules should be designed as line-replaceable units and should be accessible for repair or replacement. Nonelectrolytic (metallic) capacitors are required to ensure no performance degradation at extremely low temperatures. Additionally, a temperature switch and heating element can be included in the design so that the capacitor bank energy storage remains constant at temperatures below -40°F (-40°C). For rotary applications, any slip rings used should be periodically inspected for wear.

III.4B.8 ELECTROMAGNETIC INTERFERENCE (EMI) CONSIDERATIONS.

Laboratory EMI measurements of the ECDS have been made (references 4B-6, 4B-7) and were within the Category A and Z limits of RTCA/DO-160B Section 21.

III.4B.9 PENALTIES.

See limitations listed below.

III.4B.10 ADVANTAGES AND LIMITATIONS.

- Advantages of the EDCS System are:
 - a. Low power requirement. Power requirements are 30 to 50 times less than for hot air or electrothermal anti-icing systems. Requirements are so low that the system may be operated in all flight regimes, including takeoff and landing, without compromising engine performance.
 - b. Reliable deicing. Ice of all types—thick, thin, clear, glaze, wet—is effectively removed.
 - c. Minimum ice buildup. By cycling the system rapidly, on the order of once per minute, ice thickness may be limited to less than 0.10 inch in most conditions.
 - d. Minimal residual ice. Regardless of the firing cycle, residual ice thickness is less than 0.020 inch (0.75 mm).
 - e. No runback and/or refreezing. This eliminates a concern for some thermal systems regarding ice forming beyond protected surfaces. Advantageous in engine inlet applications.
 - f. Minimal aerodynamic penalty, during both icing and nonicing conditions. The firing cycle involves only instantaneous intrusion into the air stream during icing.

conditions. The integrated leading-edge composite installation is nonintrusive during nonicing conditions.

- g. Pilot judgment not required. The pilot does not have to determine if the ice buildup has reached a “threshold thickness,” since the system can be turned on at any time and function effectively.
- h. Retrofit application. The system can be retrofit to composite or aluminum aircraft structures. It does not need to be designed inside of the leading edge.
- i. Low electromagnetic interference. The system passes RTCA/DO-160B (references 4B-6 and 4B-7).
- Limitations of the ECDS system are:
 - a. New and not certified. The system is not presently certified on any aircraft. See reference 4B-8 for a discussion on FAA concerns for certification.
 - b. Residual ice formation. As with all mechanical deicing systems, some ice (0.005” to 0.070”) may remain on the leading edge in some conditions. This may be unacceptable for supercritical airfoils.
 - c. Noise. Noise associated with firing the coils may be discernible in the cabin or cockpit of smaller aircraft.

III 4B.11 CONCERNS.

Technical obstacles must be cleared before the ECDS is flown. Some concerns can be addressed with ground testing, minimizing expensive flight tests.

- a. Stresses and fatigue induced in the aircraft skin. The coil will induce load and stresses in the airfoil. Special strain gauge testing must be done. Such testing is discussed in reference 4B-5.
- b. Stresses and fatigue life of the outer metal strip. Aluminum or titanium alloy outer metal strips experience a small sudden deflection when the system is pulsed. Special strain gauge testing must be conducted.
- c. Power supply reliability. Endurance testing of the power supply needs to be done. Vibration testing will be required prior to actual flight.
- d. Overall system reliability. To satisfy the aircraft industry and the FAA, endurance testing of the entire system must be performed.
- e. Electromagnetic interference (EMI). EMI test results of the ECDS for the FAA are given in reference 4B-6. Good shielding and grounding of coils and cables are the key to obtaining good EMI results, thus special precautions must be taken.

- f. Lightning strikes. No lightning strike testing of the ECDS has been done.

III 4B.12 REFERENCES.

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III 4B.13 GLOSSARY.

Capacitor — A storage device for electrical energy consisting essentially of two conducting surfaces separated by an insulating material. A capacitor blocks the flow of direct current and effectively permits the flow of alternating current.

Eddy current — Current induced in the body of a conducting mass by any variation in the magnetic flux surrounding the mass.

Elastomeric — Any substance having the properties of rubber.

Electromagnetic interference (EMI) — The field of influence produced around a conductor by the current flowing through it which contributes to a degradation in performance of an electronic receiver. Also called electrical noise, radio interference, and radio-frequency interference.

Electrothermal — Electrical-resistance-generated heat used to evaporate or melt impinging cloud droplets.

Impedance — The total opposition (i.e., resistance plus reactance) a circuit offers to alternating current at a given frequency.

Inductance — Property of a circuit that tends to oppose any change of current because of the magnetic field associated with the current itself. The unit of inductance is the “henry.”

Inductive reactance — The opposition to the flow of alternating current as measured in ohms due to the inductance of a circuit.

Neoprene — Any of a group of synthetic rubbers. A nonconductor of electricity and superior to rubber in wear resistance.

Ohmic drop — A drop (loss) of an electrical current’s ability to do work as measured in ohms due to the resistance of a wire or circuit.

Phenolic (material) — Any one of several thermosetting plastic materials available which may be compounded with fillers and reinforcing agents to provide a broad range of physical, electrical, chemical, and molding properties.

Planar coil — A number of turns of wire lying essentially in a single plane and within a form made of insulating material. The wire turns introduce inductance into the electric circuit and produce a magnetic flux.

Polyurethane — A strong plastic resin that resists fire, weathering, and corrosion. A nonconductor of electricity.

Runback (ice) — The term given to ice formed from the freezing or refreezing of water leaving electro-thermal ice protected surfaces.

Silicon controlled rectifier (SCR) — A semiconductor device that functions as an electrically controlled switch for dc loads. Also known as a “thyristor.”

Single-phase (circuit) — An alternating current circuit energized in such a way that the potential between two (or all pairs of) points of entry are either in phase or 180 electrical degrees out of phase.

Three-phase (circuit) — A combination of circuits energized by alternating current where the potential between three points of entry differs in phase by one-third of a cycle (120 electrical degrees).